# On the effects of animal burrows on the performance of homogeneous earthen structures

GEO MANITOBA
BUILDING ON THE PAST

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ABSTRACT
In this study, the centrifuge models that have been designed and built to investigate the impact of animal burrows on the geotechnical performance of an existing earthen structure are described. The experiments have been conducted on a homogenous levee with 1:1 side slopes and a horizontal toe drain. Horizontal burrows of cylindrical-shaped were introduced at different elevations within the body of the levee. The upstream water level was increased until slope failure is observed. Pore pressure within the embankment and surface displacements were monitored during the experiments. Particle Image Velocimetry (PIV) was also used to determine the deformation of the levee cross section based on the images taken using three digital cameras. In this paper a summary of the test procedure and selected results will be presented. The developed failure mechanism as a result of the introduced burrows is also described.

RÉSUMÉ
Dans cette étude, les modèles de centrifugeuses qui ont été conçus et construits pour examiner l'impact des terriers d'animaux sur la performance géotechnique d'une structure en terre existant sont décrits. Les expériences ont porté sur une digue homogène avec 1:1 pentes latérales et un drain horizontal orteil. Des terriers horizontaux de forme cylindrique ont été introduits à différentes altitudes dans le corps de la digue. Le niveau d'eau en amont a été augmentée jusqu'à rupture de pente est observée. La pression interstitielle dans et déplacements de surface ont été suivis pendant les expériences. Vélocimétrie par images de particules (PIV) a également été utilisée pour déterminer la déformation de la section transversale levée sur la base des images prises à l'aide de trois caméras numériques. Dans cet article, un résumé de la procédure de test et les résultats sélectionnés seront présentés. Le mécanisme de rupture développée à la suite de l'introduction des terriers est également décrit.

## 1 INTRODUCTION

Adverse wildlife activities and their damage to earthen structures are observed worldwide. Animal burrows have been known to negatively impact the hydraulic performance and structural integrity of levees and earth dams. The yearly cost of failed earthen structures and other infrastructure due to animal burrows worldwide exceeds billions of dollars (Bayoumi and Meguid, 2011). A significant amount of the literature that is available in the area of wildlife focuses on the ecological and environmental impact of animal activities and habitat. However, studies related to the synthesis of failure mechanisms of earth structures due to wildlife activities appear to be absent from the literature. This study is intended to make a step forward in that regard.

Levee breaches are generally caused by excessive forces from the retained water, weakness in the levee material or the levee foundation, and seismic activities. Extensive research has been done to investigate the mechanisms that lead to levee breach and failure including erosion (e.g. Chen et al., 2011), overtopping (Wang and Kahawita, 2003), in addition to back analysis of previously failed levees (e.g. Steedman and Sharp, 2011).

The objective of this paper is to investigate the effects of animal burrows on the stability of levees. Emphasis is placed on the levee settlement due to induced excavations. Description of the physical model and the methodology used to create a stable burrow system in a levee body during centrifuge flight are briefly presented.

## 2 THE EXPERIMENTAL WORK

The experimental program involved the design of a two-dimensional levee model that is large enough to allow for the introduction of a uniformly distributed burrow system along the levee body and at the same time to reach failure under water pressure at a predefined g-level. The height of the levee was also chosen to allow for the burrows to be placed at different depths in order to examine the role of burrow location on the changes in the hydraulic properties of the levee and the factor of safety against slope failure. For that purpose, a series of numerical analyses was performed with different levee geometries, side slopes and water levels and the geometry that satisfied the above conditions (for the given soil properties) was chosen and used throughout this experimental study.

Centrifuge tests reported in this research were conducted at C-CORE centrifuge center in Saint John's, Newfoundland, Canada. The C-CORE center has a 5.5 m beam centrifuge with an acceleration level of up to 200g. The payload capacity is 2200 kg at 100g (Figure 1).

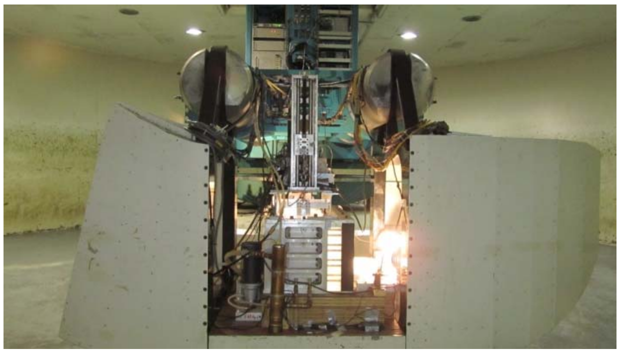


Figure 1.The C-CORE beam centrifuge with the test box on arm

## 2.1 Model configuration

The chosen levee model is 21.43 cm in height with a crest width of 11.43 cm, 1:1 side slopes and an L-shaped toe drain. Based on the internal (cross-sectional) dimensions of the plane strain box (90cm ×30cm), a scaling factor of 35 was adopted throughout the tests and the model was subjected to centrifugal acceleration of 35g. The plane strain box is equipped with a transparent face to allow for the deformation of the levee to be monitored. Figure 2 shows the details of the levee model contained within the rigid box with two main drains in both downstream and upstream sides separated from the levees model using retaining plates.

Natural Kasama soil from Japan was used to build the homogenous levee structure. The soil has been used successfully in similar centrifuge studies to investigate the effect of rainfall on the stability of earth structures (Hori et al. 2007). Some of the available physical and mechanical properties of Kasama soil are summarized in Table 1. The material is classified as Elastic Sandy Silt (MH) with plasticity index of about 26%. The soil gradation curve is presented in Figure 3.

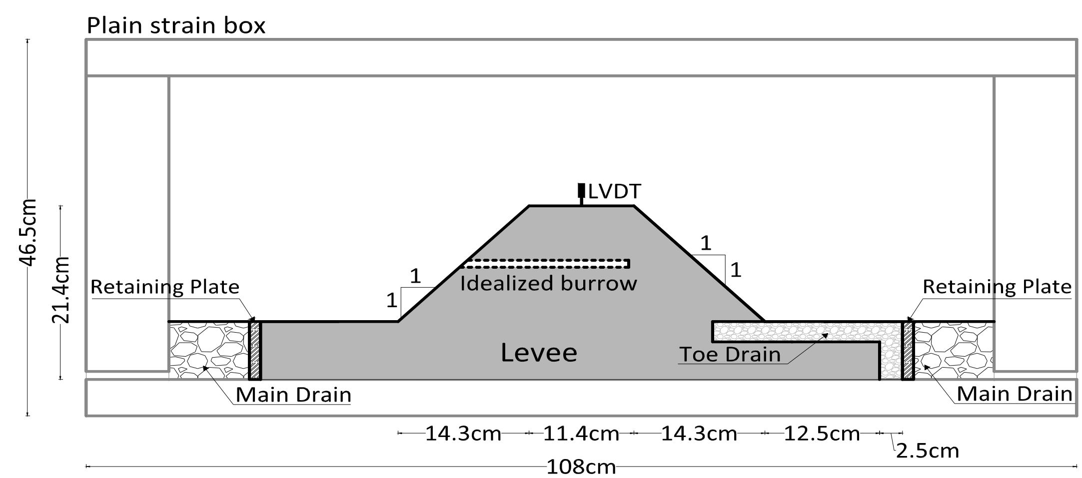



Figure 2.Model configuration

Table 1.Soil properties

| Characteristics | Kasama soil |
|---|---|
| Gravel (%) | 3.9 |
| Sand (%) | 37 |
| Silt (%) | 38 |
| Clay (%) | 21.1 |
| Particle density (g/cm$^3$) | 2.61 |
| Liquid limit (%) | 65.2 |
| Plastic limit (%) | 39 |
| Maximum dry density (g/cm$^3$) | 1.21 |
| Uniformity Coefficient | 79.82 |
| Coefficient of Curvature | 1.62 |
| Moisture content (%) | 36 |
| Friction angle | 30° |
| Cohesion (kN/m$^2$) | 15 |
| Hydraulic conductivity (cm/s) | 3.8×10$^{-3}$ |

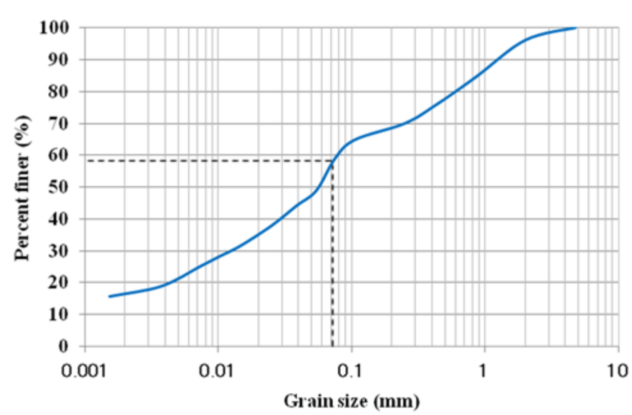



Figure 3. Gradation curve of Kasama soil

2.2 Test setup and model construction

The model was constructed using the compaction and excavation technique. This method involves two main steps. The first step is to place and compact the soil in layers of 2.5 cm thickness within the entire box up to a target height, and the second step is to excavate and remove the excess soil to shape the levee cross section. Pore pressure transducers (PPT) are also installed at selected locations to monitor the pore pressure changes during the flight. In order to monitor the deformation of the levee, three G7 digital cameras were placed outside the box facing the levee cross section. The recorded images are used in PIV analysis to track particle movement during the test. The upper surface of the levee was also meshed with white color to allow for displacement monitoring using a webcam.

Real animal burrows may differ in length, diameter and orientation. In this study, burrows were idealized using cylindrical shaped openings of the same length, diameter and elevation with respect to the levee height. These burrows need to be stable during the centrifuge spin-up to the maximum g-level and at the deigned g-level. This was achieved by installing 5 full sections and one half section of cylindrical steel rods spaced at 50 mm apart. The steel rods were pre-installed at the burrow locations during model construction (Figure 4) and were removed during centrifuge flight by means of a specially designed pullout system (Saghaee et al., 2012). To measure the settlement of the levee crest during flight, an LVDT was placed near the solid wall of the box as illustrated in Figure 4.

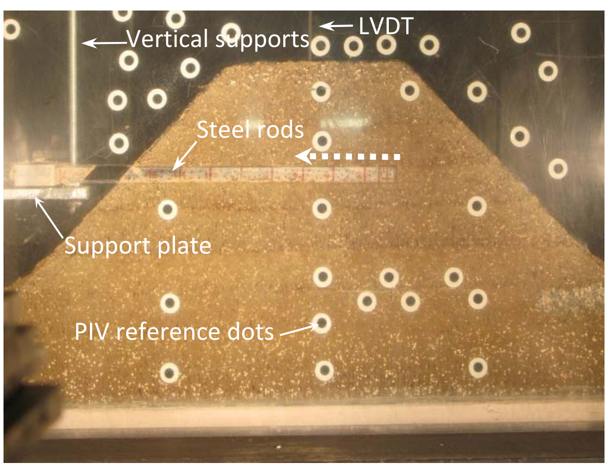
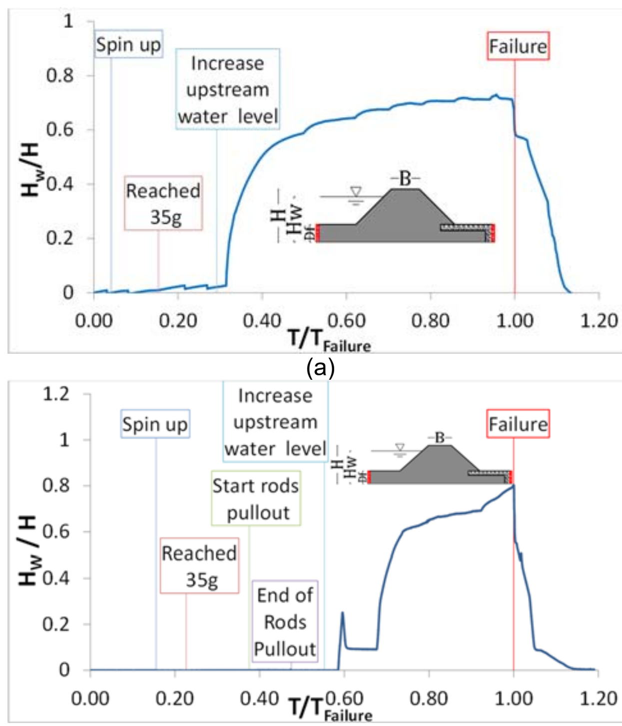



Figure 4. Model cross section with installed rods

3 TEST PROCEDURE AND RESULTS

To show the effect of animal burrows on the settlement of the levee crest two tests were chosen to be presented in this paper. The first includes an Intact Levee (without burrows) and the second includes a model with an idealized set of burrows at the mid-height of the levee. The length of the burrows was taken as 70% of the levee width at the investigated height. Centrifuge spinning started by spinning up the model to 10g. At that point the performance of the model and the installed instruments were checked to ensure that all transducers and cameras were functioning properly. In the following step, the acceleration was increased to the target level of 35g. This was then maintained throughout the test. In test 2, the rod-set pulling procedure commenced after reaching the maximum g-level with a pull out rate of 0.33 mm/sec.

After the rod removal was completed, the water level in the upstream side was increased gradually by pumping water through the upstream main drain. A special water pump was used to pump the water from the onboard water tank into the box with a controllable flow rate. The upstream and downstream water level was monitored during flight using a PPT installed at the bottom of the test box in the upstream and downstream main drains. The upstream water level (normalized with respect to the levee height) versus normalized time (with respect to failure, $T_{Failure}$); for tests 1 and 2 are shown in figure 5. The graphs show that the rate of water rise decreased with time. This is attributed to the higher seepage rate through the dam at higher water head. Therefore, the pumping rate has been modified during the test to account for this variation. In test two with mid-height burrows, the rate of water rise is slower than that measured in test 1 (intact levee). This indicates that the presence of borrows has led to an increased amount of seepage through the dam.

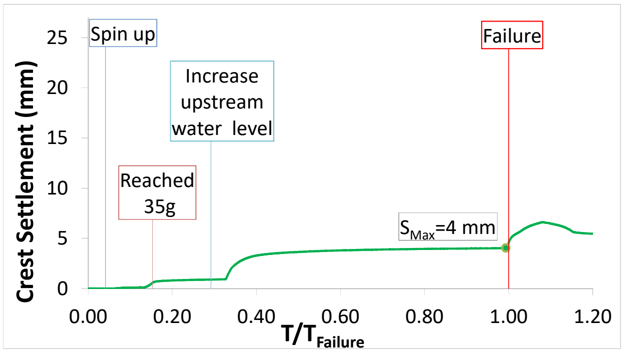



(a)

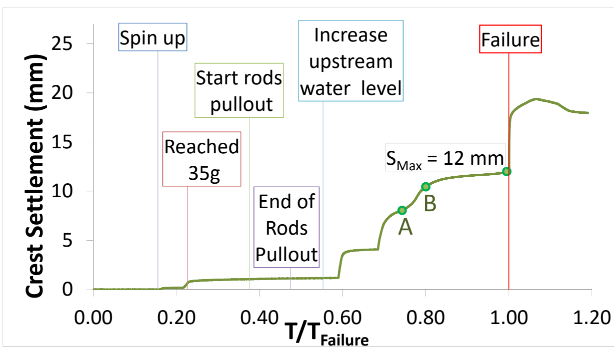
(b)

Figure 5. Normalized upstream water level a) Intact Levee b) levee with mid-height burrows

The crest settlement was also monitored during the test using an LVDT installed at the levee surface. Figures 6a and 6b present the crest settlement during the centrifuge flight. It can be seen that after reaching 35g there is a slight increase in settlement in both cases which is considered to be relatively small compared to the settlement measured at failure. In Figure 6b, the insignificant changes in settlement after reaching 35 g and up to the time of water rise suggests that the induced burrows are generally stable and did not experience much change in shape in the dry state.




(a)




(b)

Figure 6.Crest settlement of a) Intact Levee b) levee with burrow at mid-height

In both tests, increasing the upstream water level lead to a rapid increase in settlement until a stable water level is reached. The maximum settlement before failure in test 1 was measured to be 4 mm. In test 2, the settlement rate was found to change significantly during the increase in water level. Points A and B show the location of the upper and lower boundaries of the burrow. The significant movement between these two points indicates that when the water level reached the burrow location, the settlement rate started to increases rapidly. By comparing the maximum settlement right before failure in tests 1 and 2 it can be seen that the difference between these two values is 8 mm which is equal to the burrow diameter.

Figure 7 shows an image of the intact levee after increasing the water level in the upstream side. It can be seen that this settlement is almost uniform and the crest surface is more or less horizontal. In test 2, the crest settlement became non-uniform, and the settlement towards the upstream side was found to be larger than that in the downstream side. This lead to an inclined crest surface as illustrated in figure 8d. Selected images showing the incremental progress in the deformation of the levee is presented in figure 8. When the upstream water entered the burrows, soil erosion and local failure was observed around the burrow entrance and the upstream slope. The local failure zone is highlighted in figure 8c using a solid line. It was also observed that the burrow walls eroded progressively once the water started to flow through the burrow opening. This has, ultimately, lead to the collapse and flattening of the cylindrical shaped burrows. Collapsing the burrow wall is reflected as a depression of the overlying part of the levee. This is also consistent with the measured changes in crest settlement between point A and B in Figure 6b.

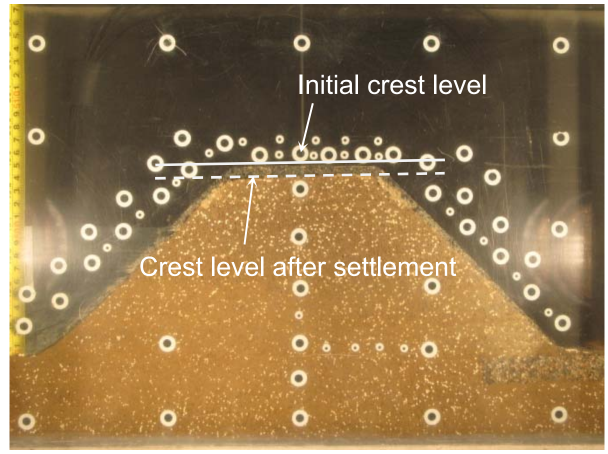



Figure 7. Settled cross section of the intact levee

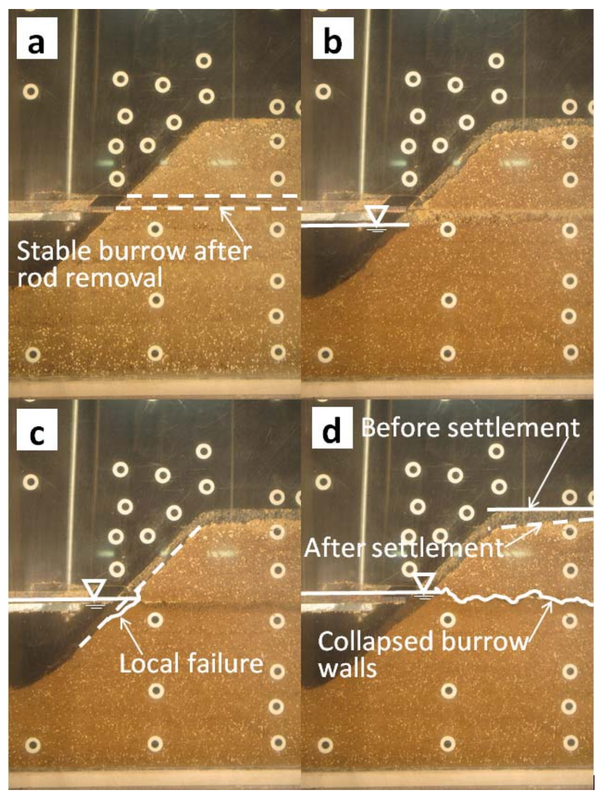



Figure 8. Levee section in test 2 during flight

## 4 CONCLUSION

This paper presented a summary of the centrifuge experiments conducted on a homogenous levee model to investigate the impact of animal burrows on the stability of the levee structure. It was found that the presence of animal burrows can have a significant impact on the stability of the deteriorated levee. Water rise in the upstream side where the burrows are present caused slope erosion following by surface settlement as a result of the collapse of burrows. As the investigated burrows extended 70% of the levee width, the non-uniform settlement was observed which can lead to further stability problems. It was also found that the levee settlement can decrease the freeboard above the maximum flood level causing overtopping. This can accelerate the failure of the impacted levee during flood events. Further investigation is needed to study the levee response to other burrow configurations.

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